

Altered intrinsic organisation of brain networks implicated in attentional processes in adult attention-deficit/hyperactivity disorder: A resting state study of attention, default mode and salience network connectivity

Authors:

Justina Sidlauskaite^a PhD, Edmund Sonuga-Barke^{a,b} PhD, Herbert Roeyers^a PhD, Jan R. Wiersema^a PhD

Author Affiliations:

^aDepartment of Experimental-Clinical and Health Psychology Ghent University, Henri Dunantlaan 2, Ghent, B-9000, Belgium

^bDevelopmental Brain-Behaviour Unit, Psychology, University of Southampton, Shackleton Building (B44), Highfield Campus, Southampton, SO17 1BJ, United Kingdom

Corresponding Author:

Justina Sidlauskaite, Department of Experimental-Clinical and Health Psychology, Ghent University

Henri Dunantlaan 2, Ghent, B-9000, Belgium

Email: Justina.Sidlauskaite@UGent.be; Tel: +32(0)9-264 94 15; Fax: +32(0)9-264 64 89

Abstract

Deficits in task-related attentional engagement in attention-deficit/hyperactivity disorder (ADHD) have been hypothesized to be due to altered interrelationships between attention, default mode and salience networks. We examined the intrinsic connectivity during rest within and between these networks. Six minutes resting state scans were obtained. Using a network-based approach, connectivity within and between the dorsal and ventral attention, the default mode and the salience networks was compared between the ADHD and control group. The ADHD group displayed hyperconnectivity between the two attention networks and within the default mode and ventral attention network. The salience network was hypoconnected to the dorsal attention network. There were trends towards hyperconnectivity within the dorsal attention network and between the salience and ventral attention network in ADHD. Connectivity within and between other networks was unrelated to ADHD. Our findings highlight the altered connectivity within and between attention networks, and between them and the salience network in ADHD. One hypothesis to be tested in future studies is that individuals with ADHD are affected by an imbalance between ventral and dorsal attention systems with the former playing a dominant role during task engagement making individuals with ADHD highly susceptible to distraction by salient task-irrelevant stimuli.

Key words: ADHD, connectivity, resting state, brain networks, fMRI

Introduction

Efficient allocation of attention is a pre-requisite for effective information processing during task performance. This requires a control system that is responsive to the dynamic nature of task demands in terms of the need for focusing, switching and dividing attention and the ability to resist distraction [1,2]. fMRI studies have identified the core brain regions implicated in attentional control. These include dorsal and ventral lateral frontal cortices, together with posterior parietal areas [3–5]. These regions form a twofold attentional control system comprised of dorsal and ventral attention networks (DAN and VAN), operating as an integrated supramodal top-down and bottom-up attentional gating system [3,6]. While traditional accounts of attentional function and dysfunction have focused on task-dependent neural activity within these networks, recent formulations have stressed the importance of a task-independent network as well [7]. This network, termed the default mode network (DMN), comprises frontal and posterior midline structures (medial prefrontal cortex, posterior cingulate cortex (PCC) with adjacent precuneus) and lateral parietal and medial temporal lobe regions [7,8]. The DMN is active during periods of rest and is attenuated following the onset of tasks [8]. The DMN is also referred to as the task-negative network, because of its anti-correlated, and to some extent antagonistic relationship to activity in attention networks (also termed the task-positive network [9]). This means that effective attentional engagement requires both - the “switching on” of the task-positive attention networks and the “switching off” of the DMN [10–12]. Indeed, there is compelling evidence that performance suffers when excess (residual) DMN activity is observed during attention demanding tasks [12–14]. Recently, Menon and Uddin [15] postulated that the salience network (SN), comprising bilateral insula and anterior cingulate cortex (ACC), provides the neural substrate of a switching hub controlling the up-regulation of attention networks and the down-regulation of the DMN. Support for this view comes from a range of recent studies [16–20].

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental condition characterised in part by symptoms of distractibility and an inability to ignore irrelevant stimuli - characteristics related to deficits in attentional control [21]. While in the past explanatory models have focused on localized deficits in brain regions, such as dorsal lateral prefrontal, posterior parietal, anterior cingulate cortices, within attention systems [22], more recent studies have examined the alternative possibility that attentional failures in ADHD during task performance may relate to interference by residual DMN activity [11]. Indeed, there is now compelling evidence from fMRI and electroencephalographic (EEG) studies that individuals with ADHD show excess DMN activity during tasks and that this has an adverse effect on their performance [14,23–25]. While the reason for this higher DMN activity during tasks remains to be determined, one possibility is that it is due to failures of the between-network switching mechanism governed by the SN [19,26]. Currently there is no direct evidence to support this hypothesis; however, it is interesting that in more general terms SN task-related activation abnormalities have been reported in ADHD [27–30]. Furthermore a number of studies also point to ADHD-related structural and volumetric abnormalities of SN regions [31].

Building on recent evidence that patterns of intrinsic task-free brain organization sculpt task-related neural processes [32,33], it has been suggested that ADHD is a condition caused by underlying deficits in brain organisation [27]. Moreover, it has been proposed that the key locus of dysfunction in ADHD may lie in the abnormal coordination of the DMN and attention networks, controlled by the SN [26,34]. In the current paper we provide the first test of this hypothesis by exploring the intrinsic organization of DMN, DAN, VAN and SN and their interactions in adults with ADHD by evaluating patterns of BOLD signal correlations measured during rest [32,35,36]. Prior resting state studies have found reduced connectivity in ADHD between DMN regions [37–39]; for opposite findings see Tian et al., [40], McCarthy

et al., [41], as well as altered organisation of DAN and VAN [21,41,42]. However, no study has directly explored connectivity within and between the DMN, DAN, VAN and SN in ADHD.

We employed a hypothesis driven anatomical, network-based, parcellation approach, which differs from more traditional seed-based voxel-wise connectivity or independent component analysis accounts. This method builds on the graph theoretical analysis approach in that it uses an anatomical atlas based on an *a priori* parcellation scheme to form the networks of interest and is not limited to a single seed region [43–45]. The use of several key regions instead of one seed to describe brain networks, enables a more comprehensive and reliable examination of the intrinsic intra- and inter-network organization [46]. Thus, this allows the direct comparison of the within- and between- brain network organisation in two different groups. In addition, this method ensures the reproducibility and comparability of the results across studies employing the same parcellation scheme, and enables the comparison of small and unequal sized samples [46]. Our predictions were as follows: i) based on the majority of previous findings we predicted hypo-connectivity between the regions comprising the DMN, DAN, and VAN in adults with ADHD; ii) based on the assumption that ADHD-related deficits in attentional control result from dysfunctional SN-DMN and/or SN-DAN/VAN coordination we predicted reduced connectivity between SN and DMN, as well as between SN and attention networks in ADHD.

Methods and Materials

Participants

The study was approved by the medical ethics committee of Ghent University Hospital. Participants gave their written informed consent before participation and received a monetary reward after participation. A total of 19 adults with an official diagnosis of ADHD obtained in a clinical setting (13 combined; 6 inattentive type) and 23 typically developing (TD) controls participated. Both groups of participants were recruited through the means of local advertising, social websites, word of mouth or from the pool of individuals who had participated in previous experiments. Participants with ADHD met the lifespan criteria for the disorder and had both - an official clinical diagnosis and research diagnosis of ADHD, confirmed by the DSM-IV-based semi-structured clinical Diagnostic Interview for Adult ADHD (DIVA; [47]). In addition, all participants with ADHD scored above cut-offs on self-report measures of childhood and adult ADHD symptoms (Wender Utah Rating Scale (WURS; [48]); Self-report questionnaire on problems of inattention and hyperactivity in adulthood and childhood; Kooij and Buitelaar [49]). All TD participants scored below the cut-offs on these questionnaires. All participants in both groups had a full scale IQ in the normal or above average range (>80) as measured by a seven subtests version of the Wechsler Adult Intelligent Scale [50]. Groups did not differ on IQ (TD: $M = 117.26$; $SD = 10.99$; ADHD: $M = 112.05$; $SD = 13.60$; $p = 0.187$), sex ratio (TD: 10 female; ADHD: 10 female), or age (TD: $M = 27.17$ years; $SD = 8.65$; ADHD: $M = 29.78$ years; $SD = 9.61$; $p = 0.365$). Nine participants with ADHD were taking stimulant medication (8 - methylphenidate and 1 - dextroamphetamine) and were asked to refrain from taking these for at least 24h prior to the experiment. Four ADHD participants were also taking antidepressant medication which they were allowed to continue (3 - selective serotonin reuptake inhibitors and 1 - bupropion

chloride). All participants had normal or corrected to normal vision, five were left-handed (1 ADHD). The general exclusion criteria were history of brain damage, a neurologic or psychiatric condition, or $IQ < 80$.

fMRI data acquisition

Functional and structural images were obtained with a Siemens Magnetom Trio MRI system (Siemens Medical Systems, Erlangen, Germany) operating at 3T, using a standard 32-channel head-coil. Study participants were positioned supine head first inside the scanner and instructed to relax and rest with their eyes closed. Structural high-resolution 1 mm^3 images were collected using a T1-weighted 3D MPRAGE sequence. Functional whole-brain images were collected in a single run of 180 whole-brain volumes lasting 6 min, using gradient echoplanar imaging (EPI) T2*-weighted sequence sensitive to BOLD contrast (TR = 2000 ms, TE = 29 ms, acquisition matrix = 64×64 , FoV = 224 mm, flip angle = 90° , slice thickness = 3 mm, voxel size $3.5 \times 3.5 \times 3.5\text{ mm}^3$, 40 axial slices). The first four EPI images of each run were discarded to reduce T1 relaxation artifacts.

fMRI data preprocessing

Data preprocessing was conducted using Statistical Parametric Mapping software (SPM8; Wellcome Trust Centre for Neuroimaging; <http://www.fil.ion.ucl.ac.uk/spm/software/spm8/>). Functional images were slice-time corrected and realigned to the first EPI. Rigid body transformation correction for within-run head motion was applied and six head motion parameters were estimated. A two-sample *t-test* analysis on the mean of absolute values of the estimated six motion parameters revealed no significant group differences in neither translational (ADHD: $x = 0.07\text{ mm}$ ($SD = 0.04$); $y = 0.09\text{ mm}$ ($SD = 0.07$); $z = 0.23$ ($SD = 0.28$); TD: $x = 0.08$ ($SD = 0.06$); $y = 0.10$ ($SD = 0.08$); $z = 0.17$ ($SD = 0.14$); *p*'s respectively:

0.722; 0.606; 0.377), nor rotational (ADHD: roll = 0.0038 ($SD = 0.0050$); pitch = 0.0021 ($SD = 0.0015$); yaw = 0.0014 ($SD = 0.0009$); TD: roll = 0.0034 ($SD = 0.0031$); pitch = 0.0019 ($SD = 0.0014$); yaw = 0.0016 ($SD = 0.0013$); p 's respectively: 0.732; 0.579; 0.702) motion.

Next, functional-to-anatomic coregistration was performed. Spatial normalization to the standard (3 x 3 x 3 mm) Montreal Neurological Institute (MNI) template was applied to functional and structural images. Functional data were spatially smoothed with an isotropic full-width half-maximum (FWHM) Gaussian kernel of 8 mm. Structural images were segmented into individual white matter (WM), grey matter and cerebrospinal fluid (CSF) masks. Data were band-pass filtered ($0.01 \text{ Hz} < f < 0.1 \text{ Hz}$), further processed and corrected using the CONN-fMRI Functional Connectivity toolbox (www.nitrc.org/projects/conn/) [51]. Sources of spurious variance such as, signal from WM, CSF (five dimensions) and movement parameters, extracted from the realignment process, were removed by linear regression. Importantly, CONN toolbox employs anatomical component-based noise correction method (aCompCor) [52] which has been shown to effectively reduce the physiological and other sources of noise in BOLD signal, and thus has proved particularly useful in increasing the sensitivity and validity of fMRI analysis [51].

Functional resting-state connectivity analysis

Anatomically landmarked regions of interest (ROIs) corresponding to areas comprising DMN, DAN, VAN and SN [7,9,53] (Table 1; Fig. 1) were derived from the Automatic Anatomic Labelling (AAL) atlas implemented in the WFU Pickatlas [54–56]. After averaging over the relevant voxels, the mean signal time series were extracted from each ROI and were used to create individual ROI-to-ROI connectivity matrices between regions corresponding to DMN, DAN, VAN and SN. Fisher's transformation was applied. Although we did not directly employ graph theoretic analysis, the brain network definitions employed here correspond to

the ones widely used in graph analysis studies. [57]. False-positive control was implemented using false discovery rate (FDR)-corrected p-values ($p < 0.05$). Adopting a ROI-to-ROI connectivity analysis, first the within-network connectivity – the product of the pairwise correlations between all the regions comprising an individual network was calculated. This resulted in a mean composite network connectivity estimate. Second, the pairwise correlations between the regions in each pair of different networks resulting in a mean composite between network correlation were computed. Hence the within- and between- network connectivity were separately estimated as the mean of pairwise ROI-to-ROI time-series correlations, i.e., between hubs within network **a** for within-network connectivity; and between hubs of network **a** and network **b** for between-network connectivity. Connectivity between all other pairs of networks was estimated in this way. Averages of within- and between-network connectivity were compared between groups.

Results

Within network connectivity: Both groups showed strong functional connectivity between regions comprising the DMN (TD: $t(22) = 12.27$, $p < 0.001$; ADHD: $t(18) = 10.02$, $p < 0.001$), DAN (TD: $t(22) = 6.90$, $p < 0.001$; ADHD: $t(18) = 9.50$, $p < 0.001$), VAN (TD: $t(22) = 6.58$, $p < 0.001$; ADHD: $t(18) = 10.41$, $p < 0.001$) and SN (TD: $t(22) = 18.58$, $p < 0.001$; ADHD: $t(18) = 11.10$, $p < 0.001$). Against our prediction, functional connectivity was stronger between areas comprising both the DMN and VAN in the ADHD group (DMN: $t(40) = 3.02$, $p = 0.002$; VAN: $t(40) = 2.68$, $p = 0.005$) and the same trend was observed for the areas comprising DAN ($t(40) = 1.53$, $p = 0.066$). ADHD and control groups did not differ in terms of between areas comprising the SN connectivity ($t(40) = 0.93$, $p = 0.179$). There is an ongoing debate about the regions comprising the DMN. We therefore examined whether the current results would hold when the set of regions comprising the DMN was extended to include additional frontal (bilateral medial frontal gyrus) and posterior (bilateral precuneus) regions. Re-running the analysis using the extended DMN did not change any of the results.

Between network connectivity: Consistent with prior studies, activity within the DAN and VAN was correlated (TD: $t(22) = 8.50$, $p < 0.001$; ADHD: $t(18) = 11.22$, $p < 0.001$), and both attention networks were anti-correlated with the DMN (DAN - TD: $t(22) = -3.88$, $p < 0.001$; ADHD: $t(18) = -2.87$, $p = 0.005$; VAN - TD: $t(22) = -1.85$, $p = 0.030$; ADHD: $t(18) = -2.43$, $p = 0.010$). The DMN and SN were positively correlated (TD: $t(22) = 4.92$, $p < 0.001$; ADHD: $t(18) = 3.43$, $p < 0.001$). There was no group difference in the strength of anti-correlations between the DMN and attention networks (DMN and DAN: $t(40) = 0.40$, $p = 0.343$; DMN and VAN: $t(40) = 1.18$, $p = 0.122$) or the DMN and SN correlation ($t(40) = 0.61$, $p = 0.271$). However, the DAN and VAN were more strongly correlated in the ADHD group ($t(40) = 2.15$, $p = 0.018$). The DAN and SN were significantly anti-correlated only in the TD group (TD: $t(22) = -2.06$, $p = 0.025$; ADHD: $t(18) = 0.96$, $p = 0.174$) producing a significant

group difference ($t(40) = -2.00, p = 0.025$). The VAN-SN connectivity was significant only in the ADHD group (ADHD: $t(22) = 2.85, p = 0.005$; TD: $t(18) = 0.66, p = 0.25$), with a trend towards a group difference ($t(40) = 1.56, p = 0.06$) (Fig. 2; table 2).

Discussion

In the current study, using resting state connectivity analyses, we tested the hypothesis that abnormalities in the intrinsic organisation of brain regions corresponding to networks implicated in attentional control - the DMN, attention networks and the SN - may lie at the heart of the pathophysiology of ADHD [26,34]. Our network-based approach to study connectivity patterns allowed us to look at both - connectivity between the key regions within networks and between these specific networks as a whole [46,58]. There were a number of findings of note that provide further evidence of connectivity abnormalities within networks implicated in attentional control in ADHD [26].

First, we found altered connectivity in ADHD with regard to the areas comprising attention networks - DAN and VAN. Two aspects of ADHD-related intrinsic organisation of regions corresponding to DAN and VAN were particularly striking. (i) The areas forming attention networks were hyperconnected, both within each network and between the networks. Moreover, (ii) the VAN and DAN displayed differential connectivity patterns with regions corresponding to SN - SN-VAN being hyperconnected and SN-DAN hypoconnected. Please note that the terms hyper- and hypoconnected relate to the absolute value of the connectivity estimates, meaning that, for instance, significantly negative connectivity in the control group compared to non-significant positive connectivity in the ADHD group is reported as hypoconnectivity in the ADHD group based on the significant difference between groups (e.g., SN-DAN hypoconnectivity in the ADHD group). The potential significance of these findings for models of ADHD pathophysiology becomes apparent once one considers the respective roles of those brain networks during the control of goal-directed and stimulus driven attention, as well as the importance of their effective coordination [3,59]. In healthy individuals the DAN and VAN systems display strong differentiation based on their specific functions to facilitate processes in attentional control [6,60]. The DAN is involved in top-

down voluntary allocation of goal-driven attention, whereas the VAN is involved in the detection of unexpected task-relevant stimuli to trigger attentional shifts, thus in stimulus-driven attention. Although they have specialised roles they continuously interact to control “where” and “what” one attends to [6,59]. Our data suggest that the DAN and VAN are less segregated functionally in ADHD. This may create altered interactions between the attention networks in ADHD, where task-relevant inputs from the DAN filter stimulus-driven signals originating in the VAN, and where task-relevant stimuli trigger the VAN to interrupt and reorient the DAN to relevant stimuli. More specifically, decreased intrinsic segregation of the attention networks may alter the information exchange threshold between the two systems with VAN signals interrupting goal-directed task-relevant DAN activity. This is consistent with recent findings that increasingly point to VAN as the locus of attentional dyscontrol and enhanced distractibility in ADHD [27,61,62]. For instance, López et al. [63] observed that in the ADHD group, but not in controls, unattended task-irrelevant distractors elicited increased VAN-related P300 activity. Our finding of increased within-VAN connectivity and the same trend in DAN may further suggest the potentially reduced flexibility and capacity to alternate between goal-driven and relevant stimulus-driven attentional processing in ADHD.

Our finding of an imbalance between SN-DAN and SN-VAN connectivity in ADHD underscores the specificity of DAN and VAN roles in attentional control. This would be consistent with the idea that increased SN-VAN coupling produces an altered saliency attribution mechanism, where the discrimination between environmental distractors and task-relevant stimuli is muted. Therefore, in the context of ADHD this might be hypothesized to relate to symptoms of distractibility and inability to ignore irrelevant stimuli. It is however difficult to directly compare our results with previous studies as a differentiation between the VAN and SN is often not made [62]. For instance, Sripada et al. [62] did not differentiate between the VAN and SN and included insula as part of the VAN. We based our analyses on

the model of the SN as a between-network switching hub, as proposed by Menon and Uddin [15], which is differentiated from the attentional networks. Hence, we separated the SN, comprised of bilateral insula and anterior cingulate cortex (ACC), from the VAN-DAN system [53,64]. The finding of a stronger SN-DAN anti-correlation in the control group, as well as a trend towards SN-VAN hyperconnectivity in the ADHD group, suggests a decreased brain network functional differentiation and adds to the frameworks where deficits in between brain networks balance are proposed to underlie ADHD. The trend to SN-VAN hyperconnectivity in ADHD suggests that attentional control deficits may be tentatively associated with VAN alterations [61,62].

Second, we reported stronger intra-DMN coupling in ADHD. The field has produced inconsistent results in this regard. While most studies have reported reduced DMN connectivity [37,38,44,62], hyperconnectivity has also been observed [40,41] (and one study found hyperconnectivity for some regions and hypoconnectivity for others within the DMN [65]). These inconsistencies may be due to differences between studies in analysis techniques used or sample characteristics. For instance, Castellanos et al. [37] used a seed-based approach and found decreased connectivity between two DMN regions - PCC and medial prefrontal cortex in an adult ADHD group. In the same sample of participants, Uddin et al. [44] applied a network homogeneity approach and showed ADHD-related reductions in only the posterior DMN, i.e., PCC. The method employed in the current study, however, was based on a network perspective where the DMN and other networks were formed of several key regions comprising that specific neural circuit. This was done in order to be able to estimate overall network connectivity using a comprehensive approach, which is different from previous seed-based connectivity or network homogeneity studies. Moreover, the current sample included adults, while other studies with a comparable network approach that reported disconnection between DMN regions were conducted in adolescent samples [38,62]. The

finding of intra-DMN hyperconnectivity in our ADHD sample appears to be consistent with the concept of resting state affinity proposed as a potential mechanism behind problems in state-to-state switching [11], with hyper-connectivity within resting networks increasing affinity for that state and reducing the potential for switching to active goal directed states. The above evidence of similar patterns of hyperconnectivity within attention networks may also be consistent with this.

Third, connectivity between DMN and attention networks, as well as connectivity between DMN and SN were unaffected in ADHD. In recent literature there has been a strong focus on the DMN as a core feature of attentional dyscontrol in ADHD. Task-based studies have provided evidence for elevated DMN levels in ADHD during task processing [14,24] which has been related to attentional deficits [11–13]. In terms of intrinsic network organization, studies have suggested diminished antagonistic relationship between DMN and attention networks which may lead to excess task-related DMN [37,62,66,67]. However, more recent models have introduced the crucial role of the SN to control the state-dependent switching between DMN and task-related attention networks [15]. Specifically, studies found support for a central role of the SN in attenuating the DMN and upregulating attention networks when switching from rest-to-task [19,20]. Interestingly, our results imply an intact between DMN and SN connectivity in ADHD, and indicate another locus of functional disorganisation that may relate to attention deficits, namely, the imbalance between SN and attention networks.

It is important to note that previous studies have suggested that brain network connectivity alterations may be differentially related to different subtypes of ADHD [68,69]. However, due to the fact that the current ADHD sample included only 6 inattentive type participants, we were unable to reliably investigate this aspect. Nevertheless, the ADHD subtype – brain network connectivity relationship is an important but underinvestigated issue and, thus, it requires further examination in future studies specifically designed for that.

Our study has some limitations that are important to address. First, our network-based connectivity method highly relies on the *a priori* choice of brain regions to form the brain networks of interest. Hence, the results strongly depend on the brain parcellation scheme used. Second, although ADHD participants refrained from stimulant medication use for a sufficient wash-out period prior to their participation in the study, history and duration of stimulant and other psychoactive medication use, such as antidepressants, which may exert differential effects on the functional brain organisation, were not taken into account in the current study. Nevertheless, this is an important aspect to be investigated in future (longitudinal) studies. Moreover, it must be noted that since this is a resting state brain network connectivity study, its findings cannot be directly compared to task-related cognitive processes, and thus, the potential links between the current results and attentional control during task performance should be seen as tentative. The role of resting state brain network connectivity in task-related processing ought to be addressed in future experiments, combining rest- and task-related brain functional properties.

Conclusions

The current findings add to the growing evidence of altered intrinsic brain organization in ADHD. Crucially, our results highlight the connectivity disturbances in attention networks and between them and SN as a putative locus for ADHD-related deficits in task engagement. An important target of investigation in future studies is the hypothesis that individuals with ADHD may suffer from imbalanced ventral and dorsal attention systems with the former playing a principal role during task engagement introducing increased susceptibility to salient but task-irrelevant stimuli.

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Tables

Table 1. Regions corresponding to the DMN, DAN, VAN, and SN and their centre of mass coordinates.

| | | Network | | | | | | | | | | |
|---------------|----------------|---------|-------------|------------|-----|-------------|----------|-----|--------------|-----------|----------|------------|
| | | DMN | | DAN | | VAN | | SN | | | | |
| Region | Superior | (R) | [5 49 30] | Middle | (R) | [35 33 34] | Inferior | (R) | [49 14 21] | (R) | [38 6 2] | |
| | medial frontal | (L) | [-8 50 30] | frontal | (L) | [-34 32 35] | frontal | (L) | [-49 12 19] | Insula | (L) | [-36 6 3] |
| | gyrus | | | gyrus | | | gyrus | | | | | |
| | Posterior | (R) | [6 -41 21] | Precentral | (R) | [40 -8 52] | Inferior | (R) | [45 -46 49] | Anterior | (R) | [7 37 15] |
| | cingulate | | | gyrus | | | parietal | | | cingulate | | |
| | gyrus | (L) | [-5 -42 24] | gyrus | (L) | [-39 5 50] | gyrus | (L) | [-43 -45 46] | gyrus | (L) | [-5 35 13] |
| | | | | Superior | (R) | [25 -59 62] | | | | | | |
| | | | | parietal | | | | | | | | |
| | | | | gyrus | (L) | [-24 59 58] | | | | | | |

Table 2. Within- and between-network connectivity differences between the ADHD and TD group.

| Network | Within-network | Between-network connectivity | | | |
|---------|---------------------|------------------------------|---------|---------------------|---------------------|
| | connectivity | DMN | DAN | VAN | SN |
| DMN | ^ ADHD | | ADHD=TD | ADHD=TD | ADHD=TD |
| DAN | ^ ADHD ^a | ADHD=TD | | ^ ADHD | ∨ ADHD |
| VAN | ^ ADHD | ADHD=TD | ^ ADHD | | ^ ADHD ^a |
| SN | ADHD=TD | ADHD=TD | ∨ ADHD | ^ ADHD ^a | |

*Results are presented with reference to the ADHD group. ^ ADHD – stronger connectivity in the ADHD group (significantly more positive in the ADHD group); ∨ ADHD – weaker connectivity in the ADHD group (significantly more negative in the TD group); ADHD=TD – no group difference; ^a – trend-level result; DMN – default mode network; DAN – dorsal attention network; VAN – ventral attention network; SN – salience network.

Figure Captions

Fig. 1 The schematic outline of the regions corresponding to the DMN, DAN, VAN and SN used in the network connectivity analyses.

Fig. 2 The schematic representation of the main intra- and inter- DMN, DAN, VAN and SN connectivity findings and differences between groups. “TD < ADHD” represents stronger connectivity in the ADHD group (significantly more positive in the ADHD group); “TD > ADHD” weaker connectivity in the ADHD group (significantly more negative in the control group); “ADHD = TD” represents the absence of group differences in connectivity strength. Please note that this scheme takes into account the absolute values of connectivity estimates as a measure of connectivity strength.

Figures

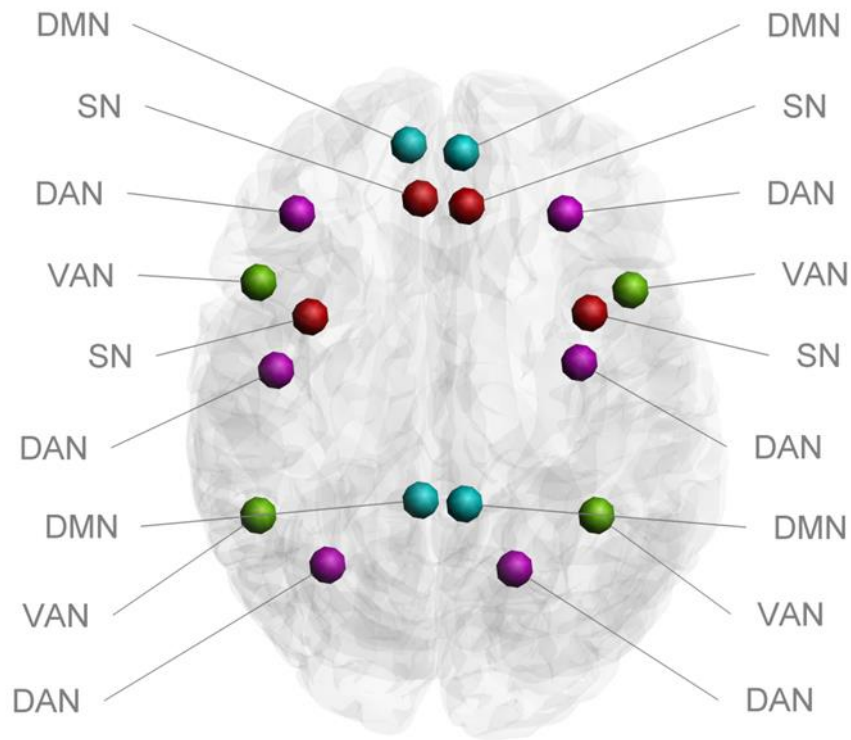


Figure 1.

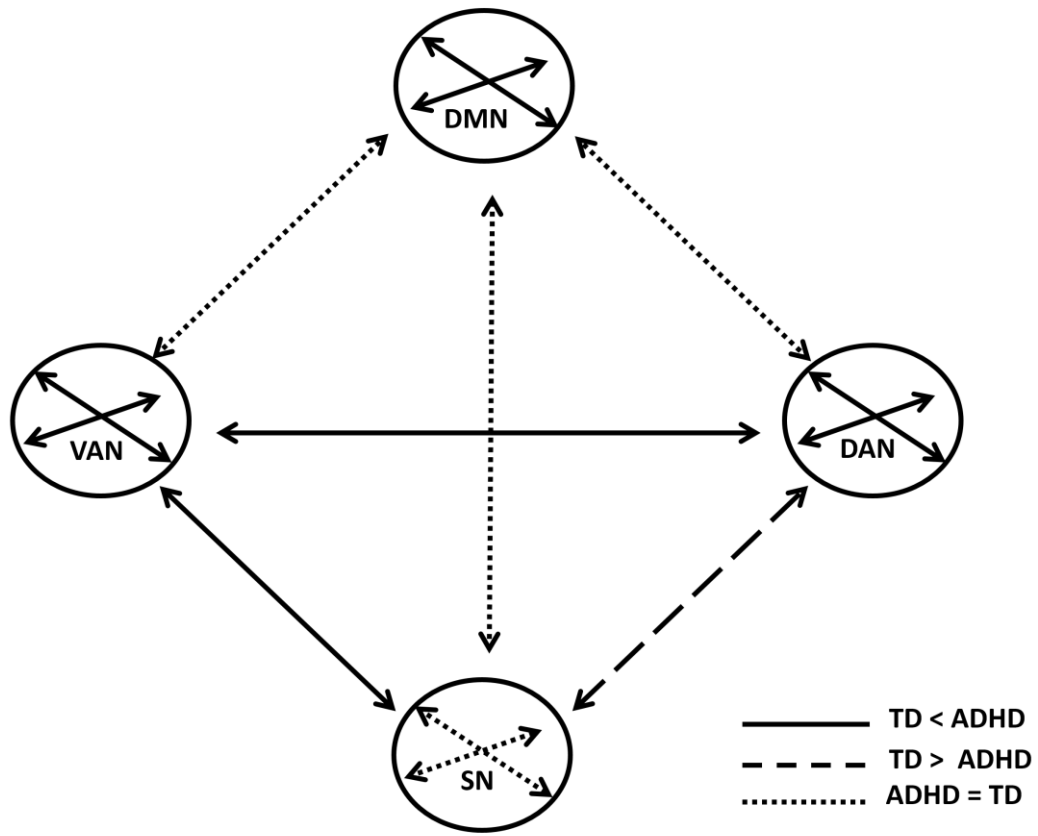


Figure 2.